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Deep Dive Topic: State of understanding of capsule modeling in context of high-foot

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State of Understanding of Capsule Modeling in the Context of the High-Foot*

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Summary:

- 1D simulation perspective: Post-shot models agree with yield data to within a factor of ~2 at low implosion velocities, but the models diverge from the data as the velocity and convergence ratio increases.
- 2D simulation perspective: Integrated hohlraum-capsule post-shot models agree with primary data for most implosions, but over predict yield and DSR for a few of the highest velocity implosions.
- High-resolution 3D post-shot capsule-only modeling captures much of the delivered performance of the one shot currently simulated.

From the 1D simulation perspective, post-shot models agree with yield data to within a factor of ~2 at low implosion velocities, but the models diverge from the data as the velocity and, somewhat equivalently, convergence ratio of the implosion increases (see Fig. 1). For implosion velocities above 370 km/s, the 1D models predict ignition in contradiction to the data. The prediction of ignition is associated with the ideal nature of 1D models and an over-prediction of fuel and hot spot areal density by ~25%. Interestingly, of the high-velocity implosions it is in fact the 165 μm ablator shot that is *closest* to the 1D models, not furthest – this is because the model captures the reduced inertial confinement that is associated with low ablator remaining mass which "turns-off" the models' tendency to ignite and propagate at high velocity.

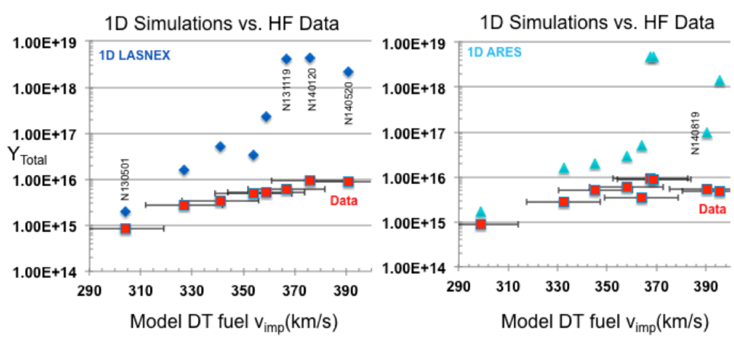

Fig 1: 1D simulations, using multi-frequency FDS drives that are calibrated to shock-timing and implosion trajectory experiments, show divergence from measurement of total neutron yield as the implosion velocity increases. Both LASNEX and ARES (and HYDRA, but not shown) predict ignition for the high-foot above 370 km/s, but this is not indicated in the data. ("mbndc" FDS source from J. Salmonson and ARES 1D model from J. Hayes). Shot N140819 (the 165 μm shell shot) is shown on the right-side plot at an implosion speed of ~390 km/s

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From the 2D simulation perspective, modest resolution integrated hohlraum-capsule post-shot models of yield performance agree with data for the lowest velocity implosions, but again diverge from the data as the velocity increases (Fig. 2)[1]. However, even for the highest velocity implosions the degree of disagreement is only a factor of ~2x for most shots. These 2D integrated hohlraum-capsule models are too low resolution to include known impactful engineering features such as the tent or fill-tube, or to capture surface finish-seeded instabilities, but are constructed to emulate the final low-modes of the implosions hot spot at bang time. These calculations imply that reducing low-mode asymmetries in the implosions could result in significant performance improvement.

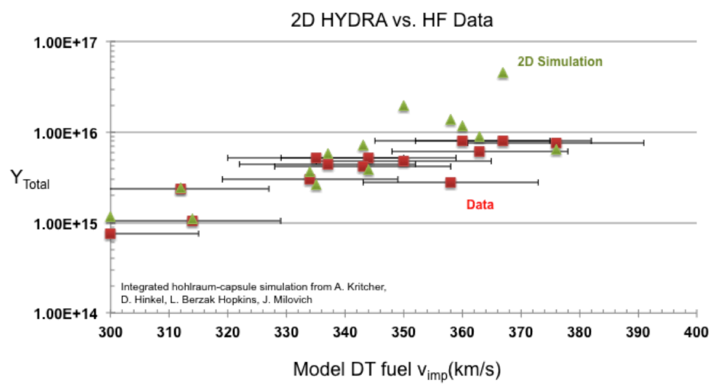
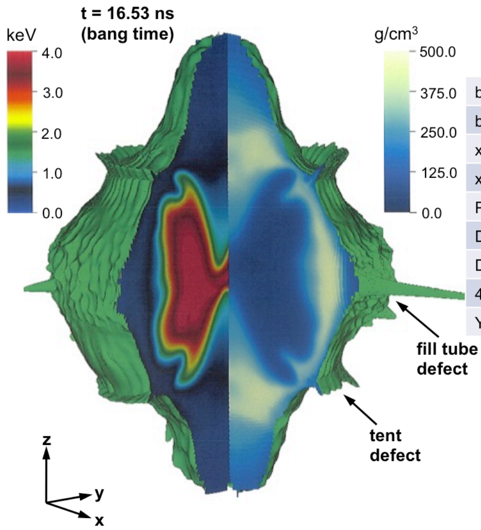


Fig 2: Similar to Fig.1, high-foot yield, from experiment and 2D integrated hohlraum-capsule simulation, is plotted against velocity (as calculated from the model that is calibrated to shock-timing, implosion trajectory, and hot-spot shape data). Unlike the 1D models, the 2D model matches most data across a range of velocities. For a few points between 350-370 km/s, the model over-estimates performance by half and order of magnitude.

High-resolution 2D capsule-only modeling (which includes ablator and DT ice layer surface characterization) of the high-foot database is ongoing. A 2D model of N140819 that includes asymmetries, measured surface roughness, and a tent, gives Y = 1.2e16 (5.47e15 measured), DSR = 4.3% (3.5% measured), T_{ion} = 4.5 keV (4.7 keV min DD measured), and P0 = 32 μm (30.7 μm measured in time-integrated x-ray). This model doesn't include the known melt defect in the capsule that was discovered at shot time, but is within the factor of two on the yield and surprisingly close on T_{ion}. Ablator optical depth data along a single line-of-sight shows no ablator remaining mass along that line-of-sight. Moreover, FNAD data imply large modulations in fuel areal density. It is possible that the melt defect perturbation on the capsule aggravated the areal mass variation and contributed to forming very thin regions of the shell that allowed the hot spot to decompress through those weak spots (enthalpy gradient driven flow) and/or burn-thru – ongoing modeling including this melt feature is suggestive of such an effect.

High-resolution 3D post-shot capsule-only modelin[2] is an extremely time-consuming process. So, while this work is ongoing, only one 3D post-shot high-foot model has been completed, for shot N130927. This model includes the engineering features of the tent membrane (using a surrogate mesh perturbation), fill-tube, capsule and DT ice layer surface roughness, capsule and DT ice layer low-mode shape, and low-mode



	N130927		
	2-D*	3-D	expt.
bang time (ns)	16.56	16.53	16.59±0.03
burn width (ps)	118	143.5	188±30
x-ray P_0 (μm)	31.3	31.4	35.3±3.0
x-ray M_0 (μm)	43.2	45.7	49.8±1.5
PNI P_0 (μm)	36.9	27.7§	32±4
DSNI P_0 (μm)	54.8	51.1§	55±4
DT T_{ion} (keV)	4.1	3.9§	4.43±0.15
4π DSR (%)	4.7	3.5§	3.48±0.17
$Y_{13-15\ MeV}$	4.4×10^{15}	3.1×10^{15}	$4.5 \pm 0.1 \times 10^{15}$

*average over three realizations
§ from single-time PMC step at bang time

Fig 3: 3D simulation of high-foot shot N130927, including the effects of surface roughness, tent perturbation, fill-tube perturbation, and low-mode drive asymmetries gives net fusion performance metrics that are close to measured.

drive asymmetries from companion hohlraum simulations. This model captures much of the delivered performance of the shot as shown in the Fig. 3 table, albeit the prolate shape at bang time is somewhat inconsistent with the observed oblate shape.

Ultra high-mode (~1200) simulations to study fuel-ablator mix in the presence of other lower mode distortions have been performed for low-foot implosions.[3] Those simulations show no significant coupling between the high modes and lower modes that dominate the hot spot. Ultra high-mode simulations of fuel-ablator mix have been performed for high-foot implosions, but not over a large enough domain to include coupling to the lowest modes. High-mode-only high-foot simulations suggest short wavelength mixing at the fuel-ablator interface should not be a problem, although this has yet to be demonstrated experimentally.

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[1] A. Kritcher, et al. "Integrated modeling of cryogenic layered High-foot Experiments at the NIF," in preparation for submission to Phys. Plasmas (2015).

[2] D. S. Clark, et al., *Phys. Plasmas*, **22**, 022703 (2015).

[3] D.S. Clark, private communication (2015).